GPR and ERT detection and characterization of a mass burial, Spanish Civil War, Northern Spain

Rubio-Melendi, David; Gonzalez-Quirós, Andrés; Roberts, Daniel; García García, María Del Carmen; Caunedo Domínguez, Amaya; Pringle, Jamie K.; Fernández-álvarez, José-Paulino

DOI:
10.1016/j.forsciint.2018.03.034

Accepted Manuscript

Title: GPR and ERT detection and characterization of a mass burial, Spanish Civil War, Northern Spain

Authors: David Rubio-Melendi, Andrés Gonzalez-Quirós, Daniel Roberts, María del Carmen García García, Amaya Caunedo Domínguez, Jamie K. Pringle, José-Paulino Fernández-Álvarez

PII: S0379-0738(18)30131-2
DOI: https://doi.org/10.1016/j.forsciint.2018.03.034
Reference: FSI 9224

To appear in: *FSI*

Received date: 31-7-2017
Revised date: 6-2-2018
Accepted date: 19-3-2018

GPR and ERT detection and characterization of a mass burial, Spanish Civil War, Northern Spain

David Rubio-Melendi[a]

Andrés Gonzalez-Quirós[a]

Daniel Roberts[a,b,c]

María del Carmen García García[d]

Amaya Caunedo Domínguez[d]

Jamie K. Pringle[b]

José-Paulino Fernández-Álvarez[a]

[a]Hydro-Geophysics and NDT Modelling Unit, University of Oviedo, Spain.

[b]School of Geography, Geology and Environment, Keele University, Staffordshire, ST5 5BG, UK.

[c]now at College of Engineering and Physical Sciences, Edgbaston, Birmingham, B15 2TT, UK.

[d]Departamento de Historia, University of Oviedo, Spain.

david@hydrogeophysicsndt.com (D. Rubio-Melendi) andres@hydrogeophysicsndt.com (A. Gonzalez-Quirós)

dlr677@student.bham.ac.uk (D. Roberts)

carmeng@uniovi.es (M.C. García García)

soledadgustavo@hotmail.com (A. Caunedo Domínguez)

j.k.pringle@keele.ac.uk (J. Pringle)

pauli@uniovi.es (J.P. Fernandez-Álvarez)

Highlights

- We detail a study of the cemetery of Oviedo (Spain), which contains a mass burial.
- GPR and ERT were used to enhance knowledge about their response to mass graves.
- The results have established the limits of the grave and the internal structure.
- We also show the importance of considering the climatology during data acquisition.

Abstract

Around 27,000 people were killed in the province of Asturias during the Spanish Civil War, with several thousands killed after the war ended. There are currently over 2,000 known mass burial locations throughout Spain, but many more are unknown. Geophysics is a useful tool employed to help in the active attempts to document and improve knowledge about victims from this conflict. This paper details a non-invasive study of the Cementerio de El Salvador, in the city of Oviedo, Northern Spain. Part of the cemetery contains a known mass burial with approximately 1,300 individuals from the Spanish Civil War and post-war repression eras. Multi-frequency near-surface geophysical techniques were undertaken, after permission, to enhance knowledge about which, if any, techniques should be used to detect, delineate and analyse such mass graves. Multi-frequency (250 MHz and 500 MHz) ground-penetrating radar surveys were acquired together with 2D and 3D Electrical Resistivity Tomography datasets. The results have established the limits of the mass grave and improve the knowledge of the internal mass grave structure. The paper also shows the importance of considering the climatic conditions during data acquisition. This has important implications for the successful detection of recent historical mass burials using near-surface geophysics.

Keywords: forensics ; geophysics ; mass graves ; Spanish Civil War

Introduction

Around 27,000 people died in the province of Asturias during the Spanish Civil War between 1936 and 1939, with about 7,000 killed for several years after the war ended [1,2]. There are currently known to be over 2,000 mass burials throughout Spain, with 357 in the Province of Asturias alone (Fig. 1) [3]. Many other mass grave locations from this period remain unknown; however, there is currently a will in Spain to locate them and dignify the memories of the victims [4–6].

Mass grave detection has been undertaken with success over the world: in 19th Century Irish mass burials [7], USA race riot victims [8], World War Two burials [9,10], in post-WW2 Polish repression mass burials [11], the Northern Ireland ‘Troubles’ (being mostly isolated burials) [12], the 1990s Balkan wars mass burials [13,14], in border crossings [15], and active civil wars with both isolated and mass burials [16].

Current forensic search methods to detect both isolated and mass clandestine burials of murder victims are highly varied and have been reviewed elsewhere [18], with best practice suggesting a phased approach, moving from large-scale remote sensing methods [19] to ground reconnaissance and control studies before full searches are initiated [20]. These full searches have involved a variety of methods, including forensic geomorphology [21], forensic botany [22] and entomology [23], scent-trained search dogs [24,25], physical probing [26–28], thanatochemistry [29] and near-surface geophysics [30–38].

The town of Oviedo, in Asturias, Northern Spain, saw early military action in 1936 during the Spanish Civil War. Afterwards, the civil (non-Catholic) part of the town's cemetery was employed as a mass burial area for the defeated. From historical accounts, it was thought that approximately 1,300 victims were executed and buried here during this period [39]. The approximate location of the burial is known and confirmed by official documents [39] and oral testimonies [40], however, the internal structure and limits of the mass grave are, at present, uncertain. After the necessary permissions were obtained [41,42], it was suggested that a near-surface geophysical investigation, using multiple techniques—Electrical Resistivity Tomography (ERT) and Ground-penetrating Radar (GPR)—may be able to:

a) Detect or delineate the boundaries of the reported mass grave.
b) Improve the knowledge of its internal structure.

Therefore, the aims of this paper are to: *firstly,* detail the near-surface geophysical results acquired at the study site, *secondly,* to improve the understanding of the geometry and, if possible, the inner structure of the mass grave; and *thirdly*, to compare results to other mass burial grave studies.

Materials and methods

Site and survey description

The Cementerio de El Salvador is located approximately 1 km SE of Oviedo, in the Province of Asturias, Northern Spain. The cemetery was divided in two -catholic and civil (non-catholic)- zones. The burial was located in the civil part, with a 3 m high wall built to separate the mass grave from the main cemetery. The area has suffered significant modifications since the 1940s: the high wall was removed in the 1970s due to family sensitivities, a perimeter stone paved road was built in 1967, and a central monument erected in 1986 in the known mass grave area. Plaques, listing the names of the victims, were installed in 2001 (Fig. 2) [39]. The existence of a mass grave on the site is well known both by official documentation and by the oral testimony of witnesses. However, the exact dimensions of the pit may not coincide with the current delimitation on the surface, because the works of such delimitation were executed 15 years after the closure of the pit (and 30 years after the beginning of the burials). This may mean that, in reality, the pit extends into the adjoining area, up to the old position of the separation wall with the Catholic cemetery (towards the NE). On the other hand, the possibility of a greater extension towards the NW and the SW is discarded due to the presence of the delimitation walls (older than the beginning of the pit), and to the SE by the presence of the access road and the civil cemetery (19th century). For this paper, the site is split into two areas of interest; (i) the accepted mass grave area (21 m x 13 m); (ii) and a potential differentiated second area where a mass burial could also be (23 m x 6 m) (see Fig. 2).

The bedrock geology consists of Upper Cretaceous siliciclastic materials of the La Argañosa formation [43]. The unit is mainly composed of sandy and clay horizons, with some gravels and conglomerates of low geomechanical quality but good hydrogeological properties [44]. Soft soils and rocks of the La Argañosa formation are easy to dig but have led to geotechnical problems (e.g. slope stability) in several engineering works in the city [45]. The site presents a smooth slope (about 2.5˚) to the SSE. Geophysical data were collected between March 2013 to May 2014 (Fig. 2), with temperatures typically ranging from 11 °C to 17 °C and monthly precipitation values ranging from 57 mm to 100 mm [46].

ERT collection and processing

The AGI SuperSting™ R8 IP system [47] was used to acquire a total of 14 profiles and a three-dimensional display in the known mass grave area (Fig. 2). 2D profiles L1 and T5 with 1 m electrode spacing were measured using a Wenner-Schlumberger array, whereas L2, T 1-4 and 6-8 with 1 m electrode spacing were acquired using both Dipole-Dipole and Wenner-Schlumberger array configurations. A 3D ERT survey, consisting of four 14-electrode lines with 1.5 m electrode spacing in longitudinal direction and 4 m in transverse direction, was also collected (Fig. 3). In the potential mass grave area, four 2D profiles were acquired where possible, with three configurations: 1 m electrode spacing and a Wenner-Schlumberger array (L5), 1.5 m electrode spacing and a Wenner-Schlumberger array (L3 and L6) and 2.25 m spacing and Dipole-Dipole array (L4) respectively.

Once the ERT data profiles were collected, they were downloaded and imported into AGI EarthImager™ 2D v.2 [48] and EarthImager™ 3D v.2 software [49] for the 2D profiles and 3D dataset respectively; and MATLAB® v.8.6 [50]. Isolated anomalous data points were removed before inversion (<5% RMS error) of apparent resistivity data to obtain "true" resistivity distributions following standard procedures [51].

GPR data acquisition and processing

In March 2014, a GPR MALÅ™ ProEx System [52] was used to collect 250 MHz and 500 MHz a grid of 2D profiles over the survey sites at 1 m survey line intervals, considered to provide resolution enough to detect the expected burial trenches of around 2 m wide. In the mass grave area (Fig. 4) 12 longitudinal profiles (19 m long) and 22 transversal profiles (11 m long) were collected. In addition, 7 longitudinal profiles (22 m long) and 24 transversal profiles (5.5 m long) were also acquired in the potential mass grave (Fig. 4). Onsite surface obstacles (e.g. the monument, plaque and trees) prevented full 3D datasets from being collected. Radar traces were at 2 cm with automatic stacks to improve signal-to-noise ratio and time windows of 200 ns and 100 ns, for 250 MHz and 500 MHz, respectively. Standard surveying methods were employed to ensure sample positioning accuracy [53].

Once 2D GPR profiles were acquired, they were downloaded and imported into REFLEX-Win™ v.6.1 processing software [54] and MATLAB® v.8.6 [50]. Processing steps were then applied to filter out non-target ‘‘noise’’ and optimise image quality. The filtering sequence included: (i) time-zero correction (ii) running average of all traces (‘‘dewowing’’); (iii) 1D Butterworth bandpass filter; (iv) background removal; (v) a gain function manually adjusted to improve the image quality in each profile; (vi) time-cut to remove blank data from the base of profiles; and (vii) an average site velocity of 0.055 $m \cdot ns^{-1}$ (consistently estimated by hyperbola matching) was used to convert the 2D profiles from two-way time (ns) to depth (m).

Results

ERT results

All ERT 2D profiles supported a consistent three layer model of the study site over both the mass and potential grave areas (Fig. 4): (1) a shallow layer of approximately 1 m depth, where relatively high values of resistivity (80 Ωm to 160 Ωm) were observed; (2) a deeper (typically 1 m to 3 m depth) middle layer that was relatively more conductive (40 Ωm to 70 Ωm); and (3) an underlying layer of increased resistivity (70 Ωm to 160 Ωm). The top layer was interpreted to be topsoil, the middle layer the mass grave area, and the deepest layer dips in every profile to the south-east following the surface topography, which is interpreted to be natural ground.

In contrast to the longitudinal ERT profiles, the transverse ERT profiles imaged two separate, relatively low isolated resistivity lows in the middle layer, that are interpreted to be separate mass grave trench areas (Fig. 5 bottom). The 3D ERT inversion of the dataset shows these two separate areas more clearly with the monument in the centre (Fig. 6).

Interestingly, collecting data over different periods of the year allows some further deductions of the targets to be given. For example, the middle conductive layer observed in all profiles shows the largest difference in wet and dry times, whereas the bottom layer beneath the mass grave is consistently more resistive in all surveys (*cf.* Fig. 7). There also appears to have some connection between layers, with some preferential water flow to the WSW which only saturates the ENE area of the site in rainy conditions.

Two differences can be remarked between mass grave and potential mass grave areas: (1) the stronger resistivity of the deepest layer (see Fig. 5), and (2) the difference in the middle layer between wet and dry conditions (see Fig. 7). The last effect can be clearly seen in Fig. 8. The difference between both areas suggests the possibility that the intermediate layer, which only appears seasonally on the outside, is not due to the presence of burials. In this way, the current surficial delimitation of the mass grave would be correct.

GPR results

In all 2D GPR profiles, the top 1 m layer (corresponding to the ERT interpreted top layer) was heterogeneous, with numerous small isolated objects present. There is then a sharp horizontal boundary to material below which significantly attenuates the radar signal in both the 500 MHz and the 250 MHz datasets (Fig. 9 and Fig. 10). This suggests that the material is conductive, which correlates with the ERT data in L2. As the signal attenuated rapidly, the deeper layer is not observable within the radar data. More near-surface isolated objects are present in the potential mass grave area that have been interpreted to be debris, tree roots, small pipes, etc. (*cf*. Fig. 9 and Fig. 10). It has to be mentioned that the high resistivity anomaly observed in Fig. 5 is also present at approximately 4 to 6 metres along the radar profile in Fig. 10. This has also been attributed to a thick tree root mass.

Discussion

In response to the *first study aim* to detail the geophysical results, this study has successfully used non-invasive, multi-geophysical methods to investigate a mass grave burial site. ERT datasets have allowed the detection of the known mass burial area. Mass grave geometries are known to be highly varied, taking the forms of a trench, pit, well organized or sectioned and with variable body densities (see [55–57]). This study shows there is internal structure inside the known mass grave, in the form of two longitudinal trenches, separated by a portion of unaltered terrain (Fig. 11). This interpretation would be consistent with some known documents where the extension of the mass grave is asked for permission in year 1939 [39] and testimonies that speak of an organized grave [40]. Fig. 11 shows a schematic representation of this type of burial with bodies stacked head over head, although testimonies [40] also suggested stacking head to feet. Geophysics, however, lacks the resolution necessary to provide information about this organization of bodies, and only can be utilized to delineate the two longitudinal trenches. The existence of a conductive intermediate layer would be associated to the position of the buried bodies. This layer extends from 1 m to 2.5 m depth in the position of the mass grave. The altered nature of the mass grave would ensure complete saturation independent of the climatological conditions, but this study has shown the importance of surveying in different climatic conditions. This important result would also be consistent with workers delineation of the mass graves carried out in 1967 for dignity of the place [39].

GPR results in both the 500 MHz and 250 MHz frequencies have not delineated the features that are present within the ERT portion of the survey. The majority of the profiles only show near-surface objects within the replaced topsoil, carried out in 1967 [39]. GPR data signal appears to attenuate once it comes into contact with the mass burial at depth, which may be due to the conductive middle layer of the site. Mid-range frequency GPR has also allowed some confirmation of isolated anomalies, although these were also imaging very near surface, non-target anomalies. Table 1 summarizes the results of both prospecting techniques in the two areas.

In response to the *third study aim* to compare results to other mass burial grave studies, there are few published studies on both the detection and characterisation of mass graves as [17] documents. 2D ERT profiles were used for a successful mass grave search, located in wooded hilly terrain in Bosnia, Eastern Europe [13]. [58] used low-frequency GPR profiles to both locate and characterise modern animal mass burial sites in the Republic of Ireland in a peatland soil environment, and [17] used low-frequency 2D GPR profiles to successfully search for a Spanish Civil War mass grave in mountainous terrain, as an outcome of this study. Finally [7] used a combination of geomorphological and GPR techniques to locate and characterise a 19th Century Irish human mass burial.

Conclusions

This forensic study on a known mass grave from the Spanish Civil War has been successfully undertaken, showing the importance of a careful desk study, and followed by a phased geophysical site investigation approach. Further work would preferably include a sensitive intrusive archaeological investigation, exhumation and re-burial of identified individuals. However, this is not planned for the foreseeable future due to the cultural and ethical sensitivities of this particular site.

As a result of this study, a subsequent search for a Spanish Civil War mass burial in mountainous terrain in Asturias was successfully undertaken, using a combination of witness statements and mid-range GPR frequency 2D profiles [17].

Role of the funding source

There was no involvement of any funding sources with this project.

Acknowledgements

The Ayuntamiento de Oviedo, victim family committee, and the workers at the Cementerio municipal de El Salvador, Oviedo, are thanked for allowing site access and fieldwork. Oscar Pelka Barreto of Keele University is also thanked for his initial research. Members of the Hydro-geophysics and NDT Modelling Unit at the University of Oviedo are thanked for logistical, equipment and software support. EU Erasmus student exchange funding had part-funded Oscar Pelka Barreto and Daniel Roberts’ MSc placement at Oviedo University.

References

[1] S. Juliá, J. Casanova, J.M. Solé i Sabaté, J. Villarroya, F. Moreno, Víctimas de la guerra civil, Temas de hoy, Madrid, 1999.

[2] C. García, P.L. Alonso, G. Álvarez, C. Cabrero, A. Caunedo, I. Díaz, Base de datos de las víctimas de la Guerra Civil y de la represión franquista en Asturias, (2011).

[3] C. García García, P.L. Alonso García, G. Álvarez Rico, C. Cabrero Blanco, A. Caunedo Dominguez, I. Díaz Martínez, Mapa de fosas comunes de Asturias, Universidad de Oviedo y Consejería de Bienestar Social y Vivienda del Principado de Asturias, 2011.

[4] A. González-Ruibal, Digging Franco's Trenches: An Archaeological Investigation of a Nationalist Position from the Spanish Civil War, J. Confl. Archaeol. 6 (2011) 97–123. doi:10.1179/157407811X13027741134102.

[5] C. Núñez, M. Baeta, L. Palencia-Madrid, L. Herrasti, F. Etxeberria, M.M. de Pancorbo, A grave in my garden. Genetic identification of Spanish civil war victims buried in two mass graves in Espinosa de los Monteros (Burgos, Spain), Forensic Sci. Int. Genet. Suppl. Ser. 5 (2015) e335–e337. doi:10.1016/j.fsigss.2015.09.133.

[6] E. Betancor, R. Fregel, M. Almeida, N.M. Suárez, J. Pestano, DNA typing for the identification of eight victims of Spanish Civil War reprisals in the Canary Islands: The case of "the Fuencaliente thirteen" mass graves (Fuencaliente, La Palma), Forensic Sci. Int. Genet. Suppl. Ser. 3 (2011) e301–e302. doi:http://doi.org/10.1016/j.fsigss.2011.09.013.

[7] A. Ruffell, A. McCabe, C. Donnelly, B. Sloan, Location and Assessment of an Historic (150–160 Years Old) Mass Grave Using Geographic and Ground Penetrating Radar Investigation, NW Ireland, J. Forensic Sci. 54 (2009) 382–394. doi:10.1111/j.1556-4029.2008.00978.x.

[8] A. Witten, R. Brooks, T. Fenner, The Tulsa Race Riot of 1921: A geophysical study to locate a

mass grave, Lead. Edge. 20 (2001) 655–660. doi:10.1190/1.1439020.

[9] S. Fiedler, J. Berger, K. Stahr, M. Graw, Localisation of a Mass Grave from the Nazi Era: A Case Study, in: K. Ritz, L. Dawson, D. Miller (Eds.), Crim. Environ. Soil Forensics, Springer Netherlands, Dordrecht, 2009: pp. 303–314. doi:10.1007/978-1-4020-9204-6_19.

[10] A. Ossowski, M. Kuś, P. Brzeziński, J. Prüffer, J. Piątek, G. Zielińska, M. Bykowska, K. Jałowińska, A. Torgaszev, A. Skoryukov, M. Parafiniuk, Example of human individual identification from World War II gravesite, Forensic Sci. Int. 233 (2013) 179–192. doi:http://doi.org/10.1016/j.forsciint.2013.09.004.

[11] Ł. Szleszkowski, A. Thannhäuser, K. Szwagrzyk, P. Konczewski, J. Kawecki, B. Świątek, Exhumation research concerning the victims of political repressions in 1945–1956 in Poland: A new direction in forensic medicine, Forensic Sci. Int. 235 (2014) 103.e1-103.e6. doi:http://doi.org/10.1016/j.forsciint.2013.12.001.

[12] ICLVR, Independent Commission for the Location of Victims Remains, (2015). www.iclvr.ie (accessed March 11, 2015).

[13] A.G. Brown, The use of forensic botany and geology in war crimes investigations in NE Bosnia, Forensic Sci. Int. 163 (2006) 204–210. doi:http://doi.org/10.1016/j.forsciint.2006.05.025.

[14] M. Djuric, D. Dunjic, D. Djonic, M. Skinner, Identification of victims from two mass-graves in Serbia: A critical evaluation of classical markers of identity, Forensic Sci. Int. 172 (2007) 125–129. doi:http://doi.org/10.1016/j.forsciint.2007.01.003.

[15] M.S. Mohd Noor, L.S. Khoo, W.Z. Zamaliana Alias, A.H. Hasmi, M.A. Ibrahim, M.S. Mahmood, The clandestine multiple graves in Malaysia: The first mass identification operation of human skeletal remains, Forensic Sci. Int. (2017) 1–9. doi:10.1016/j.forsciint.2017.05.014.

[16] SOHR, Syrian Observatory for Human Rights, (2015). www.syriahr.com (accessed May 21,

2015).

[17] J.P. Fernández-Álvarez, D. Rubio-Melendi, A. Martínez-Velasco, J.K. Pringle, H.D. Aguilera, Discovery of a mass grave from the Spanish Civil War using Ground Penetrating Radar and forensic archaeology, Forensic Sci. Int. 267 (2016) 10–17. doi:10.1016/j.forsciint.2016.05.040.

[18] J.K. Pringle, A. Ruffell, J.R. Jervis, L. Donnelly, J. McKinley, J. Hansen, R. Morgan, D. Pirrie, M. Harrison, The use of geoscience methods for terrestrial forensic searches, Earth-Science Rev. 114 (2012) 108–123. doi:http://doi.org/10.1016/j.earscirev.2012.05.006.

[19] M.E. Kalacska, L.S. Bell, G. Arturo Sanchez-Azofeifa, T. Caelli, The Application of Remote Sensing for Detecting Mass Graves: An Experimental Animal Case Study from Costa Rica, J. Forensic Sci. 54 (2009) 159–166. doi:10.1111/j.1556-4029.2008.00938.x.

[20] M. Harrison, L.J. Donnelly, Locating Concealed Homicide Victims: Developing the Role of Geoforensics, in: K. Ritz, L. Dawson, D. Miller (Eds.), Crim. Environ. Soil Forensics, Springer Netherlands, Dordrecht, 2009: pp. 197–219. doi:10.1007/978-1-4020-9204-6_13.

[21] A. Ruffell, J. McKinley, Forensic geomorphology, Geomorphology. 206 (2014) 14–22. doi:http://doi.org/10.1016/j.geomorph.2013.12.020.

[22] I. Aquila, F. Ausania, C. Di Nunzio, A. Serra, S. Boca, A. Capelli, P. Magni, P. Ricci, The Role of Forensic Botany in Crime Scene Investigation: Case Report and Review of Literature, J. Forensic Sci. 59 (2014) 820–824. doi:10.1111/1556-4029.12401.

[23] J. Amendt, C.P. Campobasso, E. Gaudry, C. Reiter, H.N. LeBlanc, M. J. R. Hall, Best practice in forensic entomology: standards and guidelines, Int. J. Legal Med. 121 (2007) 90–104. doi:10.1007/s00414-006-0086-x.

[24] A.E. Lasseter, K.P. Jacobi, R. Farley, L. Hensel, Cadaver dog and handler team capabilities in the recovery of buried human remains in the southeastern United States., J. Forensic Sci. 48

(2003) 617–21. doi:10.1520/JFS2002296.

[25] T.L.. Dupras, J.J.. Schultz, S.M.. Wheeler, L.J.. Williams, Forensic Recovery of Human Remains. Archaeological Approaches, Second Edition, CRC Press, 2011. doi:10.1201/b11275.

[26] E.W. Killam, The Detection of Human Remains, Charles C. Thomas, Springfield, Illinois, USA, 2004.

[27] A. Ruffell, Burial location using cheap and reliable quantitative probe measurements, Forensic Sci. Int. 151 (2005) 207–211. doi:http://doi.org/10.1016/j.forsciint.2004.12.036.

[28] D.W. Owsley, Techniques for locating burials, with emphasis on the probe, J. Forensic Sci. 40 (1995) 735–740. https://www.scopus.com/inward/record.uri?eid=2-s2.0-0029098541&partnerID=40&md5=ee224a67ce2b8cb47db49f5d4d4a0b92.

[29] A.A. Vass, R.R. Smith, C. V Thompson, M.N. Burnett, N. Dulgerian, B.A. Eckenrode, Odor Analysis of Decomposing Buried Human Remains, J. Forensic Sci. 53 (2008) 384–391. doi:10.1111/j.1556-4029.2008.00680.x.

[30] D. France, T. Griffin, J. Swanburg, J. Lindemann, G. Clark Davenport, V. Trammell, C. Armbrust, B. Kondratieff, A. Nelson, K. Castellano, D. Hopkins, A Multidisciplinary Approach to the Detection of Clandestine Graves, (1992).

[31] K. Powell, Detecting buried human remains using near-surface geophysical instruments, Explor. Geophys. 35 (2004) 88. doi:10.1071/EG04088.

[32] D.C. Nobes, The Search for “Yvonne”: A Case Example of the Delineation of a Grave Using Near-Surface Geophysical Methods, (2000).

[33] P. Cheetham, Forensic geophysical survey, in: J. Hunter, M. Cox (Eds.), Forensic Archaeol. Adv. Theory Pract., Routledge, NY, 2005: pp. 62–95.

[34] A. Ruffell, Searching for the IRA "Disappeared": Ground-penetrating Radar Investigation of a Churchyard Burial Site, Northern Ireland, (2005).

[35] J.J. Schultz, Using Ground-Penetrating Radar to Locate Clandestine Graves of Homicide Victims: Forming Forensic Archaeology Partnerships With Law Enforcement, Homicide Stud. 11 (2007) 15–29. doi:10.1177/1088767906296234.

[36] J.K. Pringle, J.R. Jervis, Electrical resistivity survey to search for a recent clandestine burial of a homicide victim, UK, Forensic Sci. Int. 202 (2010) e1–e7. doi:http://doi.org/10.1016/j.forsciint.2010.04.023.

[37] A. Novo, H. Lorenzo, F.I. Rial, M. Solla, 3D GPR in forensics: Finding a clandestine grave in a mountainous environment, Forensic Sci. Int. 204 (2011) 134–138. doi:http://doi.org/10.1016/j.forsciint.2010.05.019.

[38] J.R. Jervis, J.K. Pringle, G.W. Tuckwell, Time-lapse resistivity surveys over simulated clandestine graves, Forensic Sci. Int. 192 (2009) 7–13. doi:http://doi.org/10.1016/j.forsciint.2009.07.001.

[39] C. García García, Notas sobre la Fosa Común del Cementerio de Oviedo y el proceso de recuperación de la memoria histórica en Asturias, (n.d.).

[40] A. Caunedo Domínguez, J. Caunedo Domínguez, C. García, S. Tomé, Bajo valles y montañas. Geografía y memoria de la represión en Asturias, Universidad de Oviedo, AFHOSA, Ministerio de la Presidencia de España, Cooperativa Cinematográfica Latigazo, Spain, 2014.

[41] Daniel Lee Roberts, Geophysical Exploration of the Cementerio del Salvador, Oviedo, Spain, Keele University, 2014.

[42] Oscar Pelka Barreto, A Geophysical Exploration of a Mass Grave Site in Oviedo Spain, Keele University, 2013.

[43] B. González Fernández, E. Menéndez Casares, M. Gutiérrez Claverol, J.C. García-Ramos, Litoestratigrafía del sector occidental de la cuenca cretácica de Asturias., Trab. Geol. Univ. Oviedo. 24 (2004) 43–80.

[44] B. González Fernández, M. Gutiérrez Claverol, E. Menéndez Casares, Caracterización hidrogeológica de la sucesión cretácica en el sector central de Asturias (Oviedo, NO de España), Bol. Geol. Y Min. 116 (2005) 231–246.

[45] L. Pando, M.G. Claverol, G. Flor-blanco, Propiedades geotécnicas de la Formación La Argañosa (Cretácico Superior, Oviedo), Boletín Geológico Y Min. 123 (2012) 65–75.

[46] Agencia estatal de meteorología (AEMET), Valores climatológicos normales. Oviedo, (2017). www.aemet.es/es/serviciosclimaticos/datosclimatologicos/valoresclimatologicos?l=1249I&k=ast (accessed April 27, 2017).

[47] Advanced Geoscience Incorporated, The SuperSting™ with Swift™ automatic resistivity and IP system Instruction Manual, (2005) 88.

[48] Advanced Geoscience Incorporated, Instruction Manual for EarthImager 2D Resistivity and IP Inversion Software V2.4.0, (2009) 139.

[49] Advanced Geoscience Incorporated, Instruction Manual for EarthImager 3D Resistivity and IP Inversion Software V1.5.3, (2008) 100.

[50] MathWorks Inc, MATLAB® Primer, (2016) 206.

[51] M.H. Loke, Tutorial: 2-d and 3-d electrical imaging surveys, (2004) 128.

[52] MALÅ Geoscience AB, MALÅ ProEx Professional Explorer Control Unit. Operating Manual v. 2.0, (2011) 61.

[53] A.P. Annan, Electromagnetic Principles of Ground Penetrating Radar, in: H.M. Jol (Ed.), Gr.

Penetrating Radar Theory Appl., Elsevier, Amsterdam, 2009: pp. 3–40. doi:10.1016/B978-0-444-53348-7.00001-6.

[54] K.J. Sandmeier, REFLEXW 5.0, (2009) 482.

[55] L. Ríos, J.I.C. Ovejero, J.P. Prieto, Identification process in mass graves from the Spanish Civil War I, Forensic Sci. Int. 199 (2010) e27–e36. doi:http://doi.org/10.1016/j.forsciint.2010.02.023.

[56] L. Ríos, A. García-Rubio, B. Martínez, A. Alonso, J. Puente, Identification process in mass graves from the Spanish Civil War II, Forensic Sci. Int. 219 (2012) e4–e9. doi:http://doi.org/10.1016/j.forsciint.2011.11.021.

[57] W.D. Haglund, M.H. Sorg, Advances in Forensic Taphonomy Method, Theory, and Archaeological Perspectives, CRC Press, 2001. doi:10.1201/9781420058352.

[58] A. Ruffell, B. Kulessa, Application of Geophysical Techniques in Identifying Illegally Buried Toxic Waste, Environ. Forensics. 10 (2009) 196–207. doi:10.1080/15275920903130230.

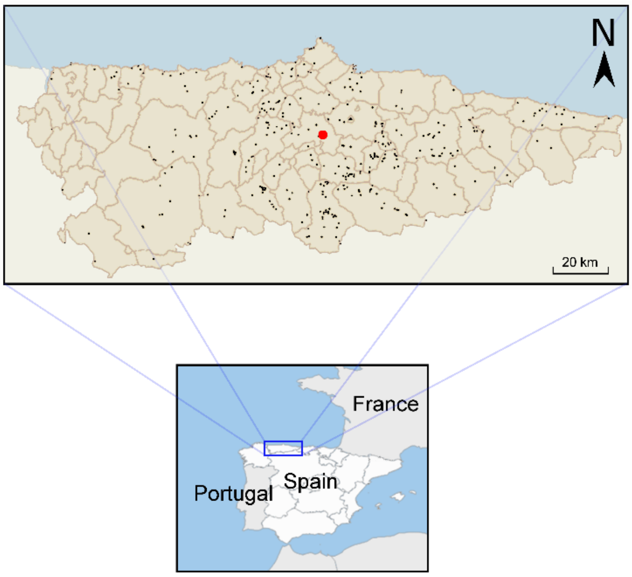

Fig. 1. Map of Asturias Province (Northern coast of Spain) showing current known positions of 357 mass graves (black dots), with this study marked (red dot). Modified from [3,17]

Fig. 2. Left: Present-day photograph of the known mass grave burial area (facing SW). Note the vertical monument (centre) erected in 1986 and the mural with the name of the victims (back).Right: aerial view of the mass grave (red), the potential mass grave area (green) and the surrounding cemetery.

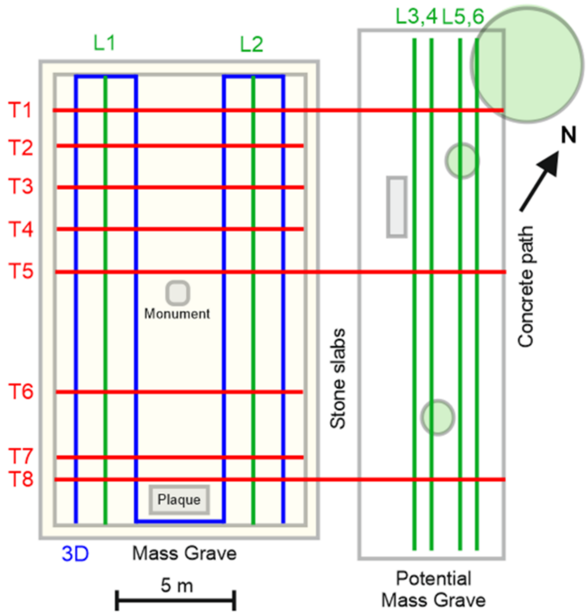

Fig. 3. Known mass grave (left) and potential mass grave (right). Marked ERT profile positions shown, surveyed in March 2013 (green), June 2013 (blue), March 2014 (red) and May 2014 (L4).

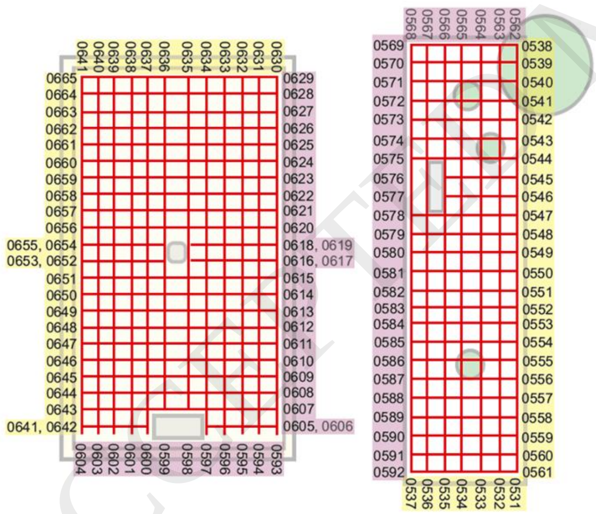

Fig. 4. Known mass grave (left) and potential mass grave (right). Ground-penetrating radar survey profile codes (Yellow = 250 MHz, Purple = 500 MHz). Modified from [41].

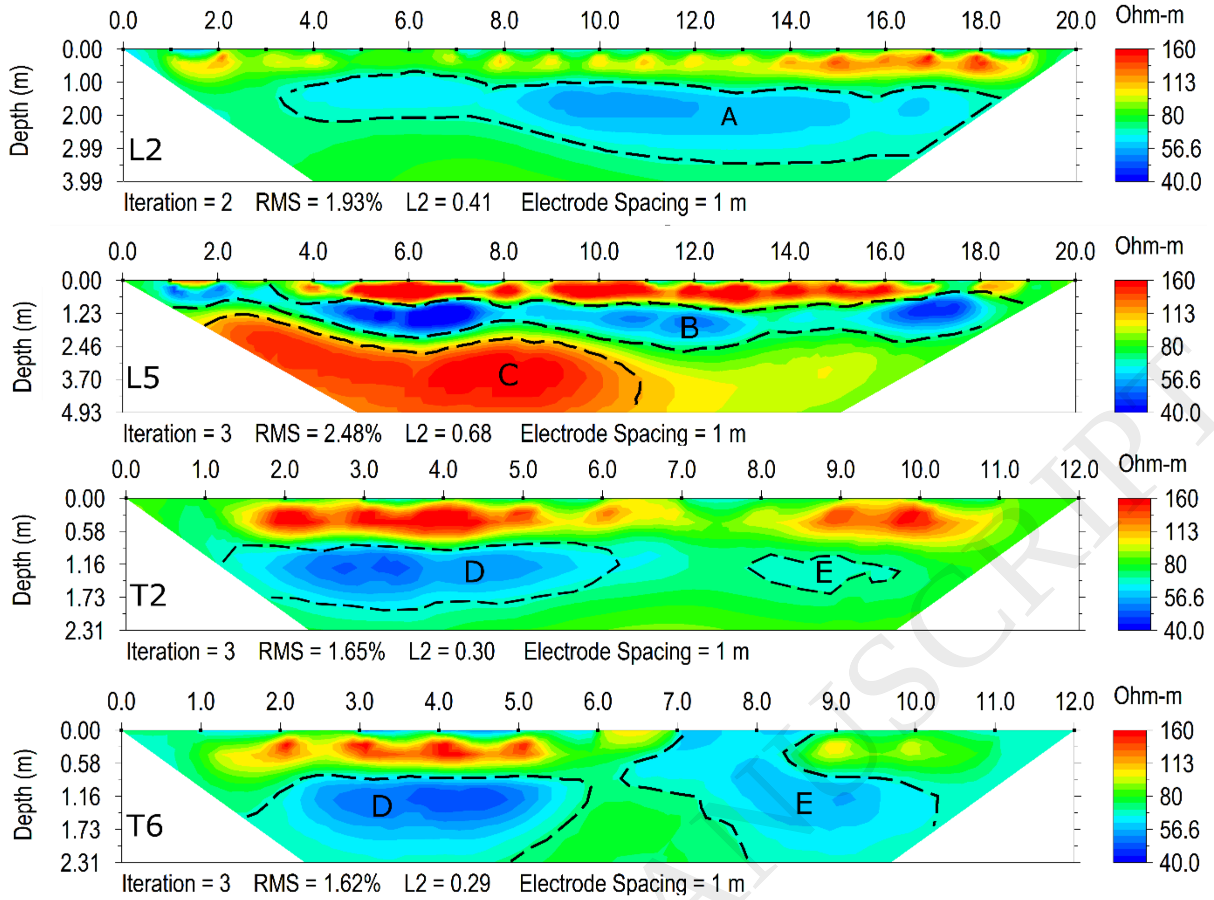

Fig. 5. ERT inverted profiles: L2 has an elongate feature (A), between 1 and 3 m below ground level, with the centre of the mass exhibiting relatively low resistivity; L5 has a longitudinally orientated NNW-SSE mass and potential grave area (B), and a relative high resistivity value (C); T2 and T6, transversely orientated WSW-ENE profiles over mass grave, has two separate low resistivity anomalies (D & E), dividing the mass grave into two distinct sections.

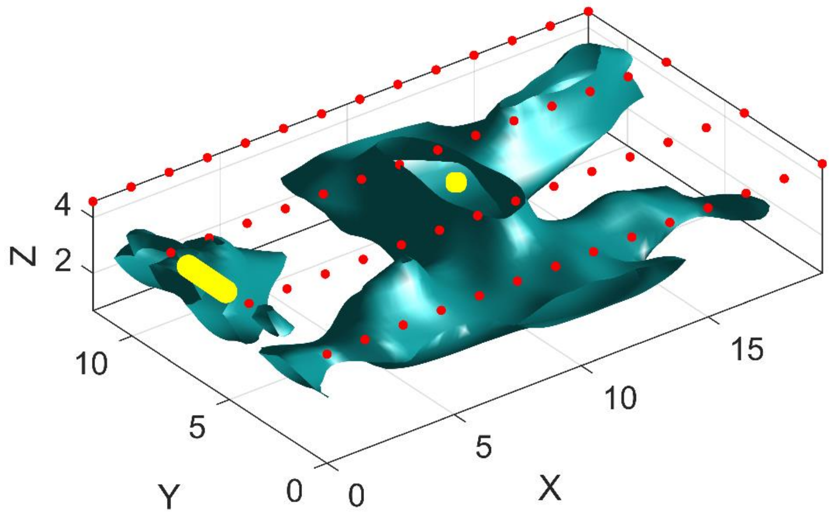

Fig. 6. 3D ERT dataset inverted with a 73 Ωm apparent resistivity value isosurface created using a smoothing kernel. Red dots indicate 3D electrode positions and yellows marks indicate the positions of the plaque and the central monument.

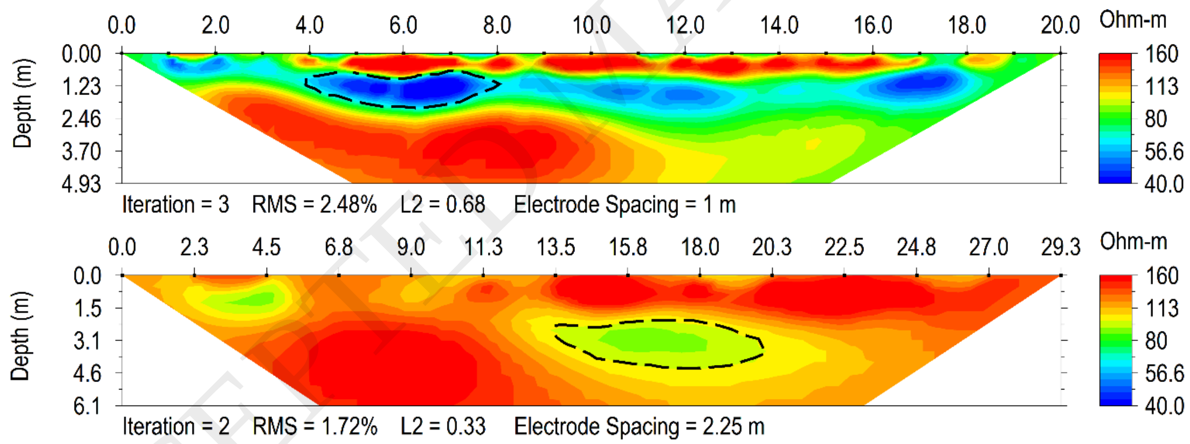

Fig. 7. ERT NNW-SSE orientated profiles L5 on a wet day (top) and L4 in dry conditions (bottom). At 6 m in L5 and 10 m in L4 recharge spots are consistently observed (dashed).

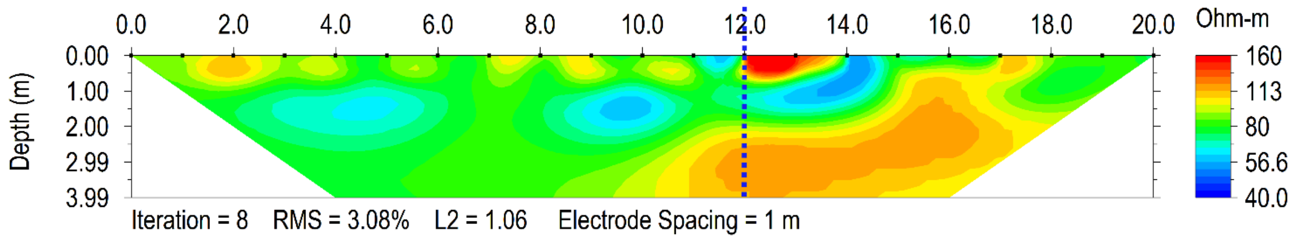

Fig. 8. Profile T8. The origin is at the WSW. Remark the 50% increased resistivity values in the materials to the right (potential mass grave) than to the left (mass grave). The dashed blue line marks the end of the known mass grave (left) and the beginning of the potential mass grave (right).

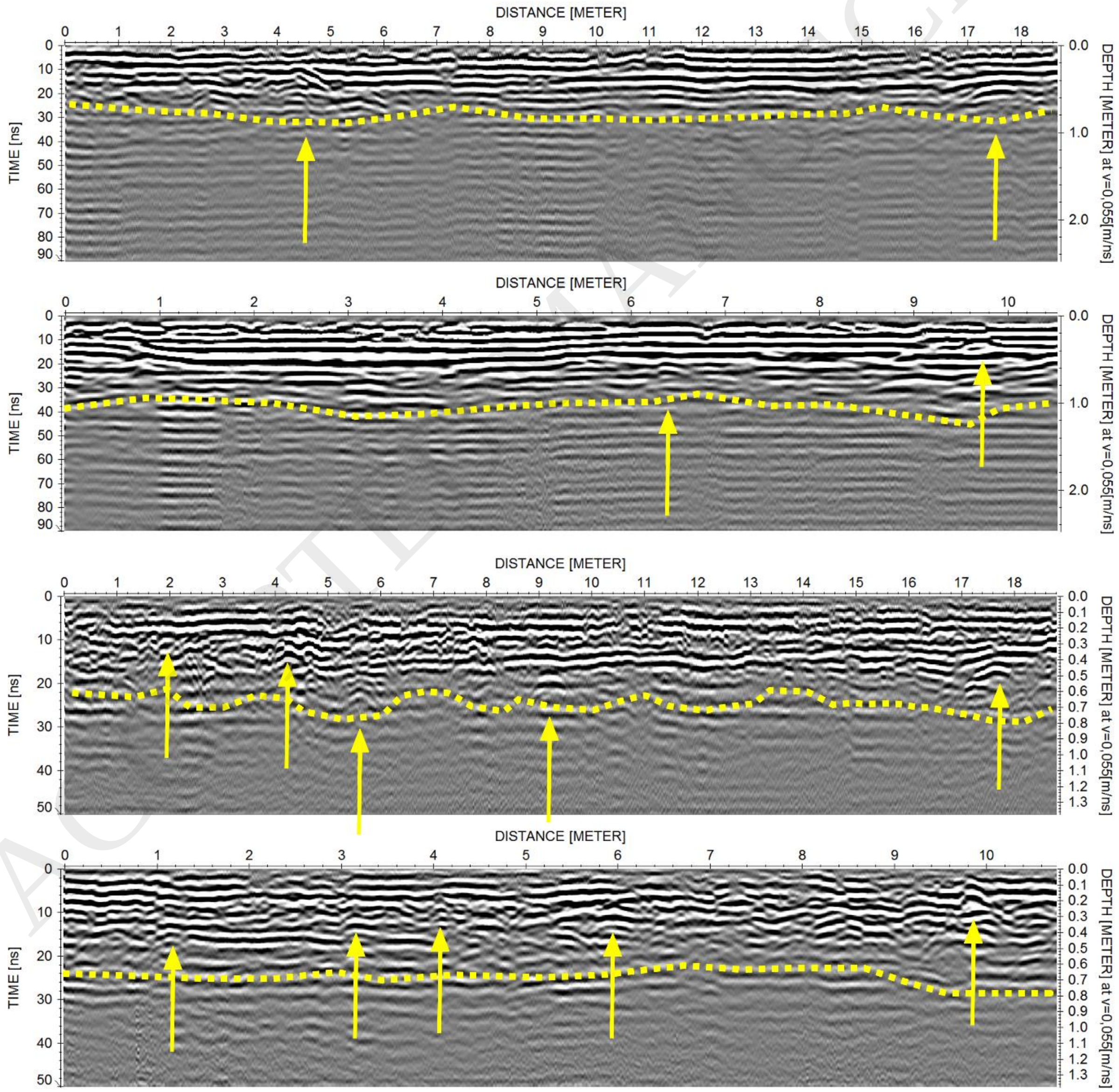

Fig. 9. From top to bottom: GPR 250 MHz longitudinal (0632, see Fig. 4), 250 MHz transversal (0648), 500 MHz longitudinal (0595) and 500 MHz transversal (0612) profiles inside the known mass grave, with the base of the feature highlighted in yellow (dashed lines) and isolated objects marked with arrows.

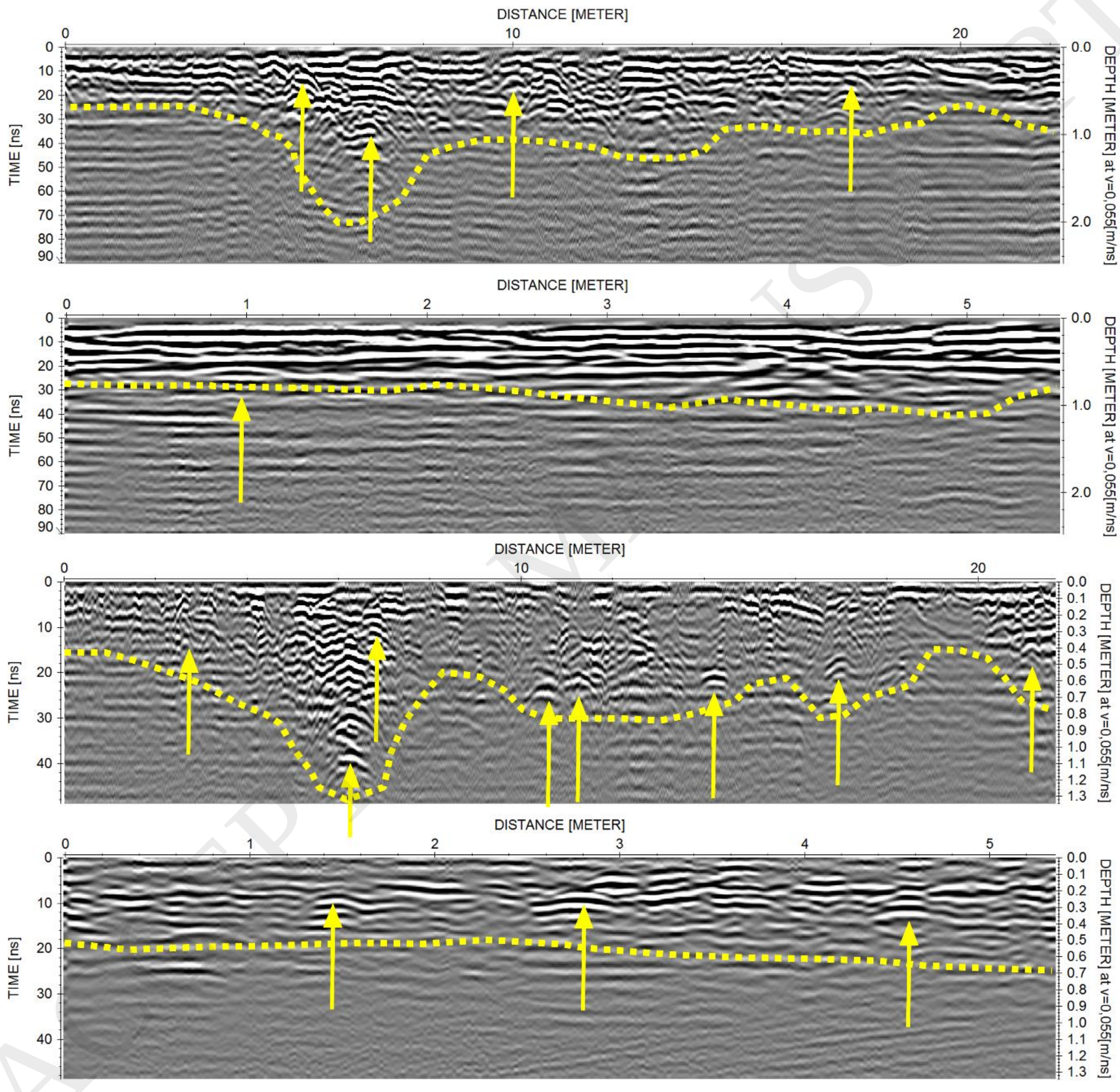

Fig. 10. From top to bottom: GPR 250 MHz longitudinal (0533), 250 MHz transversal (0551), 500 MHz longitudinal (0564) and 500 MHz transversal (0582) profiles in the potential mass grave, with the base of the feature highlighted in yellow (dashed lines) and isolated objects marked with arrows. Note an increased number of hyperbolas with respect to Fig. 9.

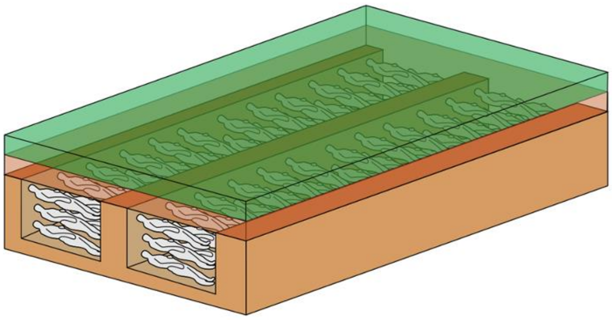

Fig. 11. Schematic reconstruction of the mass grave studied in the Cementerio de Salvador, Oviedo, Northern Spain. Modified from [41].

Table 1 Comparison of the results of both techniques in the known and potential mass grave areas.

<table>
<tr><th></th><th></th><th>Known mass grave</th><th>Potential mass grave</th></tr>
<tr><td rowspan="4">GPR</td><td>Profiles</td><td>12 longitudinal and 22 transversal</td><td>7 longitudinal and 24 transversal</td></tr>
<tr><td>Frequencies</td><td>250 MHz and 500 MHz</td><td>250 MHz and 500 MHz</td></tr>
<tr><td>Max depth</td><td>~1 m. Almost invariant with frequency</td><td>~1 m with some deeper anomalies. Almost invariant with frequency</td></tr>
<tr><td>Anomalies</td><td>Isolated hyperbolas</td><td>Agglomerated hyperbolas</td></tr>
<tr><td rowspan="5">ERT</td><td rowspan="2">Profiles</td><td>2 longitudinal, 4 longitudinal for 3D inversion and 5 transversal.</td><td>4 longitudinal and 3 transversal</td></tr>
<tr><td colspan="2">3 transversal connecting both areas</td></tr>
<tr><td>Arrays</td><td>10 Wenner-Schlumberger, 8 Dipole-Dipole profiles and one 3D</td><td>6 Wenner-Schlumberger profiles and 3 Dipole-Dipole profiles</td></tr>
<tr><td>Max depth</td><td>Variable with length. Up to ~6 m</td><td>Variable with length. Up to ~6 m</td></tr>
<tr><td>Anomalies</td><td>2 conductive areas (from ~1 m to ~3 m in depth) separated by a more resistive line</td><td>Conductive area, only in wet conditions</td></tr>
</table>